

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

14/Response
P. Walker
3-31-03

In re application of:
Heideman et al.

Serial No.: 09/693,803

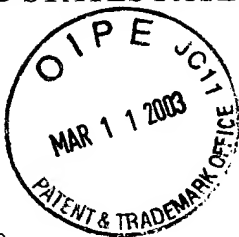
Filed: October 20, 2000

For: INTEGRATED OPTICAL
LIGHTGUIDE DEVICE

Examiner: Kang, Juliana

Group Art Unit: 2874

Confirmation No.: 8677



Attorney Docket No. 080743165002

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RESPONSE TO OFFICE ACTION

In response to the Office Action mailed September 6, 2002, the applicant wishes
the Examiner to consider the following information:

By way of background regarding a segmented waveguide sensor, any waveguide
with its axis in the z direction with light of a given angular frequency ω may propagate along in
certain electric field patterns, every pattern having its specific propagation speed. Such patterns
are called modes which may be described by the expression $E^i(x, y, z, \lambda, t) = E^i(x, y, \lambda) \exp j(\omega t -$
 $k_o N_{eff}^i(\lambda) z)$, where $E^i(x, y, \lambda)$, the pattern, is called the field profile of the mode i at a wavelength λ
and $N_{eff}^i(\lambda)$ the effective index, being directly related to the propagation speed of the mode i,
 c/N_{eff}^i , where c is the propagation speed of light in a vacuum. k_o is proportional to ω and
inversely proportional to wavelength λ .

Field profile and effective index depend upon refractive indices of materials constituting the waveguide and the geometry of the waveguide. One can design waveguides in which only one mode may propagate, the so-called monomodal waveguides. Well known waveguides are glass fibers and integrated optical waveguides.

A simple example of an integrated optical waveguide structure includes a bottom buffer layer, a middle core layer and a top cladding layer. It is required that at least the refractive index of the core layer is greater than the refractive indices of the cladding and buffer layers. An ordinary waveguide does not vary along the propagation direction of the light, the z axis, meaning that its refractive index distribution does not vary with the z coordinate. Also, waveguides consisting of an alternating series of segments of two different types may be made where each type of segment is z directional invariant. Segments of different types, of course, differ in their refractive index. Segments of the same type can also show different values along the z direction.

A well known segmented structure is referred to as a grating, a series of identical segment-couples placed adjacent to each other along the z direction. This grating may be referred to as a periodical structure with a period L . This structure is generally applied for the gradual transfer of power from a launched mode i to another mode j of identical vacuum wavelength λ . This transfer is possible only if the coupling condition is obeyed: $N_{eff}^i(\lambda) - N_{eff}^j(\lambda) = \text{integer} \cdot \lambda/L$.

Given a certain length of the grating, the speed of the power transfer depends upon the coupling constant. The greater the constant, the greater the difference between the segments. The grating can transfer the power to an identical mode which propagates in the

opposite direction when $2N_{eff}^i = \text{integer} \cdot \lambda/L$. Hence, the mode is reflected against a grating and such a reflective grating is called a Bragg grating.

If modes of a variety of wavelengths are impinging on a grating, only the mode with a wavelength obeying the relationship $2N_{eff}^i = \text{integer} \cdot \lambda/L$ will be reflected. Modes of other wavelengths will be transmitted and a particular reflection curve will be obtained. Because of this, Bragg gratings are often applied as wavelength filters.

In integrated optical sensors, one often uses the principle of evanescent field sensing. On top of the core layer a thin layer of an active material is provided. Here, active means that its optical properties, such as its refractive index or its absorption coefficient are sensitive to a certain physical or chemical parameter. If the refractive index is sensitive, it is called a refractive sensor. Here, the change of refractive index of the active material leads to a change in both the effective index $N_{eff}^i(\lambda)$ and the field profile $E^i(x, y, \lambda)$.

In the subject application, there is described a segmented waveguide comprising at least two types of segments, as shown in the drawings. It is noted that in these drawings, both types of segments differ with respect to the cladding material only. In one type of segment, the cladding material is merely a passive material, in the other type, the cladding is an active material having a refractive index sensitive to the parameter that is to be measured, the measurand. The measurand may be a chemical concentration, for example. Assume that at zero concentration, the refractive indices of the passive cladding material and the active cladding material are identical. Although both materials have different chemical compositions, they behave identically with respect to waveguiding. Hence, in this state, the mode does not experience the presence of segmentation and light will propagate in the same way as if it was a z-invariant waveguide. This state is called the working point of the sensor. If the refractive

indices are different, the value of the effective indices N_{eff} and the field profiles are also different. The sensor disclosed in the subject application exploits the differences in field profiles.

At each transition (the boundary between two adjacent segments) of a monomodal waveguide, part of the power of the guided mode is transferred to the guided mode of the next segment as a consequence of the difference in the field profiles of the two modes. The remaining part is radiated outwardly. The amount of power that is radiated outwardly at a transition is greater, the greater the difference in refractive indices of the segments. The sensor principle is that the greater the differences in refractive indices of the cladding material, the smaller the amount of power transferred to the guided mode of the next segment. Due to the small value of this refractive index difference, only a very small part of the power will be radiated out and a large number of segments are positioned in series to enhance the effect. Hence, the transfer function of the sensor, i.e., the output power divided by the input power, is a measure of the unknown parameter.

It is to be noted that no periodicity is required. This sensing structure is not a grating although a periodical segmented structure, the grating, will show the same effect. Also, this sensor does not rely on grating assisted coupling from one mode to the other. A coupling condition, as explained earlier, is irrelevant. If a periodical segmentation, grating, is chosen, the effect would not rely on a change of one of the parameters in the coupling condition but rather on the change of the coupling constant. Due to the small differences in refractive indices, reflection from a transition is negligible. In case of a periodical segmentation, this would imply that under the Bragg condition, the coupling strength is too small to have appreciable back reflection.

Cited Art

The cited art will now be discussed but it is noted that all the cited references are based upon grating or periodical segmentation and sensing whereas, the invention described in the subject application is non-periodical segmentation. More particularly, the patent to DiBin et al., No. 5,280,172 ('172) describes a device having a grating, and one of the segment types contains the active material. Also, in the '172 patent the refractive indices of the passive and active materials are very close to each other giving transparency (no losses, or output power is identical to the input power) in the case where both are identical. So in the '172 patent, it is the coupling strength of the grading that is primarily varied. In the '172 patent reflective power is measured and while measuring the transmission is mentioned only, this is seen as reflection. In the '172 patent, losses are neglected with the consequence that at very small refractive indices differences, where the coupling strength is very small, the reflection should also be very small. However, at these small refractive indices differences, just the losses at the transitions are dominant in determining the output power.

The '172 patent requires a periodical segmentation whereas the invention of the subject application does not. In the subject application, due to the small differences in refractive indices, the basic effect of power loss through radiation differs from the basic effect of reflection as mentioned in the '172 patent and as a consequence the manner of optimizing the two devices, the '172 device and the device of the subject application are different.

The patent to Starobudov, No 6,058,226 ('226) is constructed of fibers such that the field profiles of the ordinary guided modes are completely confined within the fiber. The fiber is insensitive to activity outside the fiber. Hence, if an active material was applied on the outside of the fiber, the guided modes will not experience any change due to the active layer. Further, other types of modes can propagate through the fiber, the cladding modes. In signal

transport they are never applied because they are very sensitive to changes in the environment and they are generally strongly attenuated by outside contamination or by bending of the fiber. The first property, sensitivity to the environment, makes them attractive for sensing. The idea behind this sensor is to couple power from the ordinary mode to a cladding mode. This can occur only if the coupling condition is obeyed. Hence if the refractive index of the active material changes, the effective index for all wavelengths is changed also. This means that while the coupling condition is obeyed by a mode couple of particular wavelength, the wavelength of the light that will be coupled is changed. Because the cladding mode shows a high attenuation, this overcoupled power will be lost with long propagation distances. Thus, when offering broadband light to the fiber in the transmitted spectrum, one wavelength will be missing and the value of this wavelength is a measure for the unknown parameter. Some variations of this principle are given generally involving more gratings. Using a certain type of grating allows for the obtaining of an MZI. Another variation has a character of a Fabry Perot resonator sensor.

The sensor in the '226 patent is based on a completely different principle from that described in the subject application. Coupling to a mode that is sensitive to the measurand where one determines the change in coupling condition by observing the minimum in the transmitted spectrum. The grating is used to provide mode coupling. In the subject application, only one single intensity is measured whereas in the '226 patent, a whole spectrum has to be recorded.

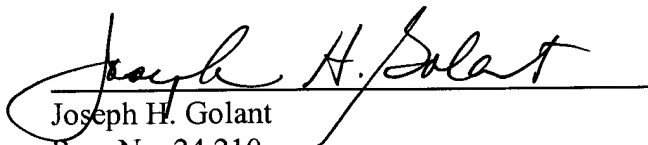
The patent to Murphy, No. 5,864,641 ('641), has a sensing device that appears to be identical to the basic device in the '226 patent. The second device disclosed is a simple Bragg grating sensor. Cladding of the fiber has been removed locally to obtain a sensing window where the active material can be applied directly on top of the core material of the fiber.

Changes of refractive index influences the value of N_{eff} in the ordinary mode so that the wavelength of the reflective light depends on the value of the unknown parameter. There is no comment about removing the cladding without damage to the core of the fiber. Thus, the conclusion reached as to the '226 patent applies to the '641 patent and when the '641 patented device is used as a Bragg sensor, operation is based on mode coupling by a grating, something different from that disclosed in the subject application.

In view of the above comments, the Examiner is respectfully requested to reconsider the claims of the present application and indicate their allowance.

Dated: March 6, 2003

Respectfully submitted,


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